Differential and Integral Cross Sections of the Reactions C^{12} (d,α) B^{10} and O^{16} (d,α) N^{14} in the Deuteron Energy Range from 15 MeV to 20 MeV

Takuji YANABU,*1 Sukeaki YAMASHITA,*1 Teruo NAKAMURA,*2 Kunio TAKAMATSU,*3 Akira MASAIKE,*4 Shigeru KAKIGI,*2 Dai Ca NGUYEN*2 and Kiyohiko TAKIMOTO*2

(Kimura Laboratory)

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Angular distributions of alpha particles were obtained when the C^{12} nucleus was bombarded by deuterons with energies from 15.1 MeV to 19.7 MeV, leaving the residual uncleus B^{10} in its ground, first, third and fourth excited states. Also were obtained the angular distributions of alpha particles when the O^{16} nucleus was bombarded by deuterons with energies ranging from 14.9 MeV to 19.6 MeV, leaving the residual nucleus N^{14} in its ground and second excited states.

Numerical values of the differential cross sections are listed in tabuler form for these reactions and are also given the integral cross sections calculated from these results.

1. Introduction

In our laboratory, (d,α) reactions on a series of light nuclei have been investigated since 1960.[1),2),3),4),5),8)] The members of nuclides which have been studied so far, were Be^9, B^{10}, B^{11}, C^{12}, N^{14} O^{16}, F^{19}, Ne^{20}, Mg^{24}, Al^{27}, P^{31} and S^{32}.

The energy of the incident deuteron beam was about 15 MeV, which was extracted from the Kyoto University cyclotron and was focused on a target at the center of a scattering chamber. When these nuclides were bombarded by 15 MeV deuterons, many types of reactions such as (d,p), (d,n), (d,t), (d,α) and so on could occur, but special attention was paid to distinguish the alpha particles leaving the residual nuclei in their ground and lower excited states. In those (d,α) reactions we have investigated, the C^{12} (d,α) B^{10} and O^{16} (d,α) N^{14} reactions attracted our interest in two points; first, the cross sectins of these reactions were very much larger than other (d,α) reactions[3)], secondly, the angular distribution of the alpha particles corresponding to the ground or lower excited states of the residual nuclei showed predominant backward peaking.

It is not easy to understand the mechanism of the (d,α) reaction, since this reaction is one of the composite particle reactions, but following the current view

*1 柳父琢治, 山下佐明

*2 中村輝男, 柿木茂, ニュエン・ダイ・カ, 滝本清彦 Department of Physics, Faculty of Science, Kyoto University.

*3 高松邦夫, Now at the Institute for Nuclear Study, University of Tokyo.

*4 政池 明 Now at the Department of Physics, Faculty of Science, Nagoya University.

of the nuclear reaction, alpha particles emitted in the backward region in the center of mass system are considered to be produced by an exchange or heavy particle stripping process. This understanding correlates to the alpha cluster model of the C^{12} and O^{16} nuclei.

If the backward peaking is due to the heavy particle stripping, it may be suggested that an exchange effect occur in some favourable energy range of the incident particle. So an experiment was planned to see whether angular distributions and integrated cross sections of C^{12} (d,α) B^{10} and O^{16} (d,α) N^{14} reaction depend on the incident deuteron energy. In the following, the results of the experiment done at the Institute for Nuclear Study, University of Tokyo, are given in tabular forms, a part of which has been already reported[5].

2. Experimental Procedures and Results

The deuteron beam from the energy variable cyclotron of the Institute for Nuclear Study, University of Tokyo, was deflected by a steering magnet and then brought to focus on the center of a scattering chamber by a pair of quadrupole magnets. Polystyrene film of about 0.2 mg/cm thickness was used as a C^{12} target, and natural oxygen gas of about 20 cm Hg in pressure was used as a O^{16} target. Alpha particle detection was done by a p-n junction type solid state radiation detector, and its reverse bias voltage was adjusted to fit the depletion depth to the alpha particle energy.

Deuteron energies were 15.1, 15.9. 16.7, 17.5, 18.2, 19.0 and 19.7 MeV in the C^{12} (d,α) B^{10} reaction, and were 14.9, 15.4, 15.7, 16.0, 16.5, 16.9, 17.3, 18.1, 18.8 and 19.6 MeV in the O^{16} (d,α) N^{14} reaction.

Reasults obtained are shown below in tabular forms, and the abbreviations used in these tables are,

α_0 : alpha particles leaving the residual nucleus in its ground state.

α_1,etc : alpha particles leaving the residual nucleus in its first excited state and so on.

E_d : incoming deuteron energy in the laboratory system.

$\theta_{C.M.}$: angle between the direction of the detected alpha particle and the direction of the incident deuteron in the center of mass system.

$(d\sigma/d\Omega)_{C.M.}$: differential cross sections in the center of mass system.

Error : essentially statistical error.

In Table 1, the experimental results of the C^{12} (d,α) B^{10} reaction are exhibited. Table 2 shows the results of the O^{16} (d,α) N^{14} reaction. Integral cross sections are given in tables 3 and 4, for the C^{12} (d,α) B^{10} reaction and the O^{16} (d,α) N^{14} reaction respectively.

Table 1. Numerical values of cross sections for C^{12} (d,α) B^{10} reaction.

(a) C^{12} (d,α_0) B^{10} g'nd.

E_d=15.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.1	3.16	3
25.4	4.34	2.5
31.7	4.81	2.5
37.9	5.22	2.5
44.0	4.27	2.5
50.1	3.25	3
62.1	1.66	4
73.7	1.39	5
84.9	1.57	5
95.7	1.50	5
105.9	1.10	6.5
115.7	1.67	5.5
124.9	2.58	4.5
133.7	2.68	4.5
142.1	2.22	5.5
150.1	2.95	5
157.9	3.80	4.5
165.4	5.44	4
169.1	5.70	4

E_d=15.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.1	4.44	2
25.4	5.02	1.5
31.7	4.98	2
37.9	4.52	1.5
44.0	3.76	2
50.1	3.17	2
62.1	1.84	3
73.7	1.47	2
84.9	1.94	3
95.7	2.03	3
105.9	1.63	3.5
115.7	1.79	3.5
124.9	2.90	3
133.7	3.10	3
142.1	2.62	3.5
150.1	2.76	2.5
157.9	3.34	2.5
165.4	4.05	3
169.1	3.96	3
172.7	4.30	3

E_d=16.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.0	5.24	1.5
25.3	6.14	1.5
31.6	5.88	1.5
37.8	4.82	1.5
44.0	3.65	2
50.1	2.18	2
56.1	1.97	3
62.0	1.62	2.5
67.9	1.38	3.5
73.6	1.27	3
81.8	1.97	2.5
95.5	2.22	2
105.8	1.76	2.5
115.5	1.77	3
124.8	2.44	2.5
133.6	2.88	2
142.0	2.55	2.5
150.1	2.31	3
157.8	3.15	2.5
165.3	4.35	2
172.7	5.24	2

E_d=17.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.0	4.20	2
25.3	5.13	1
31.6	5.47	1.5
37.8	4.78	1
44.0	3.80	2
50.1	2.57	1.5
56.1	1.73	3
62.0	1.25	2.5
67.9	0.85	4.5
73.6	0.95	3
79.2	1.16	4.0
84.8	1.75	2.5
95.5	2.06	2.5
105.8	1.88	2.5
115.5	2.21	2.5
124.8	2.36	2.5
133.6	2.61	2.5
141.0	2.18	3
150.1	2.08	3
157.8	2.70	2.5
165.3	3.83	2.5
172.7	5.29	2

Table 1. (continued)

E_d=18.2 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.0	3.50	2
25.3	4.88	2
31.6	5.92	1.5
37.8	5.61	1.5
43.9	4.58	2
50.0	2.62	2.5
56.0	1.67	3
62.0	0.98	4
67.8	0.78	4.5
73.5	0.86	4.5
79.2	1.17	4
84.7	1.57	3.5
95.4	1.84	3
105.7	1.78	3.5
115.4	1.99	3.5
124.7	2.12	3.5
133.5	2.29	3.5
142.0	2.31	4
150.0	2.25	4
157.8	2.79	3.5
161.6	2.30	3.5

E_d=19.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.0	2.93	2.5
25.3	4.35	2
31.6	5.50	1
37.8	5.27	1.5
43.9	4.36	2
50.0	2.55	2.5
56.0	1.34	3
62.0	0.84	4.5
67.8	0.86	4.5
73.5	1.00	4
79.2	1.25	4
84.7	1.44	3.5
95.4	1.80	2.5
105.7	1.87	3.5
115.4	1.91	3.5
124.7	1.85	4
133.5	1.81	4
142.0	1.88	3
150.0	2.03	4
157.8	2.26	3.5
165.3	3.29	3.5
169.0	3.84	3

E_d=19.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
18.7	2.87	2
24.9	3.62	2
31.0	4.82	2
37.2	4.73	2
43.2	3.97	2
49.2	2.61	2.5
55.1	1.53	4
61.0	0.96	4
72.5	1.18	3.5
83.5	1.34	4
94.2	1.34	3.5
104.4	1.70	3.5
114.2	1.77	4.5
123.5	1.38	5
132.5	1.26	3.5
141.0	1.38	4.5
149.2	1.43	3.5
157.2	1.58	3
164.9	2.26	4
168.7	2.59	4

Table 1. (continued)

(b) C^{12} (d,α_1) B^{10} 1st

E_d=15.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.2	8.21	2
25.6	5.11	2.5
31.9	5.63	2
38.1	6.15	2
44.3	4.73	2.5
50.5	2.79	3
62.5	0.91	6
74.2	1.73	4.5
85.4	2.00	4
96.2	2.02	4.5
106.4	2.66	4
116.2	2.94	4
125.4	3.24	4
134.2	2.4	5
142.5	2.18	5.5
150.5	2.80	5
158.1	4.11	4.5
165.6	6.53	3.5
169.2	7.59	3.5

E_d=15.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.2	5.49	1.5
25.5	4.14	2
31.8	3.95	2
38.1	4.07	1.5
44.3	3.11	2
50.4	1.87	3
62.4	0.93	4.5
74.1	1.83	2
85.3	2.24	3
96.1	2.30	3
106.3	2.50	3
116.1	2.64	3
125.3	2.37	3.5
134.1	1.82	4
142.4	1.77	4.5
150.4	1.90	4.5
158.1	2.89	2.5
165.5	4.20	3
169.2	5.00	3
172.8	5.82	3

E_d=16.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.2	4.38	2
25.5	3.18	2
31.8	2.77	2.5
38.1	2.20	2
44.2	1.66	3
50.4	1.31	2.5
56.4	0.92	4
62.4	0.78	3.5
68.3	0.94	4.5
74.0	1.41	2.5
85.3	1.85	2.5
95.0	1.73	2.5
106.3	2.02	2.5
116.0	1.95	2.5
125.3	1.31	3.5
134.0	1.14	3
142.4	1.11	4
150.4	1.25	4
158.1	1.82	3.5
165.5	2.12	3
172.8	2.20	3

E_d=17.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.1	3.32	2
25.5	2.76	1.5
31.8	2.36	2.5
38.0	1.54	2
44.2	1.00	4
50.3	0.98	3
56.4	1.16	3.5
62.3	1.03	3
68.2	1.08	4.0
74.0	1.23	3
79.6	1.45	3.5
85.2	1.52	2.5
95.9	1.38	3
106.2	1.45	3
116.0	1.42	3
125.2	1.10	3.5
134.0	0.85	4
142.3	0.70	5
150.3	1.03	4.5
158.0	1.48	3
165.5	1.48	3
172.8	1.51	2.5

Table 1. (continued)

E_d=18.2 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.1	1.70	2.5
25.5	1.93	2.5
31.7	2.30	2.5
38.0	1.61	3
44.2	0.77	4.5
50.3	0.67	4.5
56.3	1.01	4
62.3	1.27	3.5
68.1	1.21	3.5
73.9	1.19	4
79.6	1.38	3.5
85.1	1.37	3.5
95.9	1.22	4
106.1	1.28	4
115.9	1.21	4.5
125.1	0.77	6
133.9	0.77	6.5
142.3	0.68	7
150.3	0.80	7
158.0	1.27	5.5
161.7	1.25	5.5

E_d=19.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.1	1.59	3
25.4	1.49	3
31.7	1.90	2
37.9	1.53	3
44.1	0.68	4.5
50.2	0.50	5.5
56.2	0.96	4
62.2	1.24	3.5
68.1	1.30	3.5
73.8	1.25	3.5
79.5	1.40	3.5
85.0	1.39	3.5
95.8	1.00	3
106.0	1.09	4.5
115.8	1.03	5
125.0	0.53	7
133.8	0.66	7
142.2	0.69	5
150.2	0.91	5
157.9	1.16	5
165.4	0.99	6.5
169.1	1.10	6

E_d=19.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.1	1.54	3
25.5	1.53	3
31.7	1.49	3
38.0	1.22	3
44.2	0.83	4
50.3	0.76	4.5
56.3	0.98	4
62.3	1.25	3.5
73.9	1.42	3.5
85.1	1.32	3.5
95.1	0.93	4.5
106.1	0.93	5
115.9	0.81	5.5
125.1	0.50	7.5
133.9	0.41	6
142.3	0.56	7.5
150.3	0.83	4.5
158.0	0.84	4
165.5	0.95	6.5
169.1	0.76	7.5

Table 1. (continued)

(c) C^{12} (d,α_3) B^{10} 3rd.

E_d=15.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.5	2.26	3
26.0	2.30	3
32.4	1.63	4
38.7	1.18	5
45.0	0.90	5.5
51.2	0.43	8
63.4	0.89	6
75.2	0.81	6.5
85.6	0.58	8
97.4	0.84	7
107.7	0.85	7
117.4	0.66	8.5
126.6	0.94	7.5
135.2	1.15	7
143.4	1.32	7
151.2	0.89	20
158.7	0.88	30
166.0	1.71	27
169.5	1.91	27

E_d=15.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.5	1.96	2.5
25.9	1.76	3
32.3	1.43	3
38.6	1.26	2.5
44.9	1.05	3.5
51.1	0.95	4
63.3	0.89	4
75.1	0.44	3.5
86.4	0.37	7
97.2	0.63	5.5
107.5	0.47	7
117.2	0.42	7.5
126.4	0.73	6
135.1	1.25	5
143.3	1.34	5
151.1	0.79	12
158.6	1.38	24
165.9	1.98	10
169.5	2.33	14
173.0	3.35	14

E_d=16.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.4	2.73	2
25.9	2.02	2.5
32.2	1.64	3
38.6	1.26	2.5
44.8	1.13	3
51.0	0.91	3
57.2	0.74	5
63.2	0.64	3.5
69.1	0.45	6.5
74.9	0.31	5.5
86.3	0.31	5.5
97.1	0.41	5
107.3	0.37	6
117.1	0.33	6.5
126.3	0.62	5
134.9	1.47	2.5
143.2	1.59	3.5
151.0	1.18	4
158.6	1.19	4.5
165.9	2.96	3
173.0	4.85	2

E_d=17.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.4	2.42	2.5
25.8	2.02	2
32.2	1.67	3
38.5	1.27	2.5
44.8	0.92	4
51.0	0.67	3.5
57.1	0.55	5
63.1	0.50	4
69.0	0.45	6
74.8	0.38	5
80.6	0.29	8
86.1	0.25	6
96.9	0.26	6.5
107.2	0.29	6.5
116.9	0.23	7.5
126.1	0.62	4.5
134.8	1.39	3.5
143.1	1.32	4
151.0	1.14	4
158.5	1.40	4
165.8	2.62	3
172.9	4.17	7.5

Table 1. (continued)

E_d=18.2 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.4	1.78	2.5
25.8	1.44	3
32.1	1.36	3
38.4	1.21	3
44.7	1.01	4
50.9	0.66	4.5
57.0	0.48	6
63.0	0.37	6.5
68.9	0.40	6.5
74.7	0.37	7
80.4	0.38	7
86.0	0.37	7
96.8	0.22	9
107.1	0.23	9.5
116.8	0.33	8.5
126.0	0.44	8
134.7	0.84	6
143.0	1.27	5
150.9	1.58	5
158.4	1.85	4.5
162.1	2.19	4.5

E_d=19.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.3	1.19	3
25.7	0.86	4
32.1	0.99	3.5
38.4	0.99	4
44.6	0.95	4
50.8	0.59	5
56.9	0.42	6
62.9	0.35	6.5
68.8	0.42	6.5
74.6	0.51	5.5
80.3	0.48	6
85.9	0.44	6.5
96.7	0.21	7
107.0	0.30	8.5
116.7	0.40	8
125.9	0.47	8
134.6	0.66	7
142.9	0.82	6.5
150.8	1.20	5.5
158.4	1.75	4
165.7	2.50	4
169.3	3.40	3.5

E_d=19.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.3	1.06	3.5
25.7	0.85	4
32.1	0.81	4
38.4	0.78	4
44.6	0.72	4.5
50.8	0.53	5
56.9	0.32	7
62.9	0.29	7
74.6	0.49	6
85.9	0.42	6.5
96.7	0.13	12
107.0	0.22	10
116.7	0.42	7.5
125.9	0.35	14
134.6	0.49	5.5
142.9	0.76	6.5
150.8	0.69	10
158.4	0.95	14
165.7	2.16	4.5
169.3	2.71	4

Table 1. (continued)

(d) C^{12} (d,α_4) B^{10} 4th.

E_d=15.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.9	2.59	3
26.5	3.07	3
33.0	2.60	3
39.5	2.36	3
45.9	2.36	4
52.2	1.12	5
64.6	0.42	8
76.5	0.37	9.5
88.0	0.51	8.5
98.9	0.52	8.5
109.2	0.78	8
118.9	0.81	13
128.0	1.10	12
136.5	0.86	19
144.6	1.29	18
152.2	1.03	29

E_d=15.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.8	1.12	3
26.4	1.37	3
32.9	1.51	3
39.3	1.60	3
45.7	1.22	4
52.0	0.83	4
64.4	0.28	7.5
76.3	0.28	4.5
87.7	0.47	6
98.6	0.61	5.5
108.9	0.90	5
118.6	1.22	4.5
127.7	1.02	5
136.3	1.17	15
144.4	0.62	27
152.0	1.44	25
159.3	1.87	23
166.4	1.00	36
169.8	1.96	25

E_d=16.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.7	1.00	3.5
26.3	1.07	3.5
32.8	1.17	3.5
39.2	1.22	2.5
45.6	1.05	4
51.9	0.73	3
58.1	0.42	6
64.2	0.26	5.5
70.2	0.22	9
76.1	0.26	6
87.5	0.58	4
98.3	0.72	4
108.6	0.85	4
118.3	1.48	3
127.5	1.48	3
136.1	1.17	3
144.2	0.85	5
151.9	1.94	3.5
159.2	2.91	3
166.3	2.95	3
173.2	3.88	12.5

E_d=17.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.6	0.95	4
26.1	1.07	2.5
32.6	1.03	4
39.0	0.91	3
45.3	0.85	4
51.6	0.63	3.5
57.7	0.43	6
63.8	0.31	6
69.8	0.24	8.5
75.7	0.28	5
81.4	0.47	6
87.0	0.68	3.5
97.9	0.53	4.5
108.2	0.69	4
117.9	1.21	3.5
127.0	1.41	3
135.7	1.23	4
143.8	0.71	5
151.6	0.94	14.5
159.0	2.10	13
166.1	2.78	13
173.1	3.65	12.5

Table 1. (continued)

E_d=18.2 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.6	1.03	3.5
26.1	0.85	4
32.6	0.77	4
39.0	0.64	4.5
45.3	0.53	5
51.6	0.41	6
57.7	0.40	6
63.8	0.33	7
69.8	0.36	6.5
75.7	0.42	6.5
81.4	0.56	5.5
87.0	0.62	5.5
97.9	0.55	6
108.2	0.43	7
117.9	0.79	5.5
127.0	0.87	5.5
135.7	0.70	7
143.8	0.65	7.5
151.6	0.92	6.5
159.0	1.55	10.5
162.6	2.00	4.5

E_d=19.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.6	1.11	3.5
26.1	1.25	3
32.5	1.27	2.5
38.9	0.96	4
45.2	0.54	5
51.4	0.36	6
57.6	0.34	6.5
63.7	0.35	6.5
69.6	0.44	6
75.5	0.49	5.5
81.2	0.49	6
86.8	0.44	6.5
97.7	0.47	6.5
108.0	0.44	7
117.7	0.49	7
126.8	0.49	7.5
135.5	0.50	8
143.7	0.52	8
151.4	0.82	7
158.9	1.48	5
166.1	1.85	5
169.6	2.79	4

E_d=19.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
19.6	1.49	3
26.1	1.71	2.5
32.5	1.68	3
38.9	1.32	3
45.2	0.82	4
51.4	0.44	5.5
57.6	0.29	7
63.7	0.32	7
75.5	0.40	6.5
86.8	0.33	7.5
97.7	0.37	7
108.0	0.46	7
117.7	0.47	7
126.8	0.37	18.5
135.5	0.27	31
143.7	0.55	12.5
151.4	0.72	20
158.9	1.26	13.5
166.1	2.10	14.5
169.6	5.12	14

Table 2. Numerical values of cross sections for O^{16} (d,α) N^{14} reaction

(a) O^{16} (d,α_0) N^{14} g'nd

E_d=14.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.3	1.03	3
29.1	0.90	2
34.9	1.01	3
40.6	1.05	3
46.3	1.09	3
57.5	0.54	3
68.5	0.33	3
79.2	0.18	8
89.7	0.23	5
99.8	0.36	5
109.7	0.35	5
119.2	0.43	5
128.5	0.26	8
137.5	0.55	5
146.3	1.17	5
154.9	1.33	5
159.1	1.00	5

E_d=15.4 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
17.5	0.95	1
23.3	0.81	1
29.1	0.70	2
34.9	0.78	2
40.6	0.88	3
46.3	0.89	3
57.5	0.48	3
68.5	0.27	5
39.2	0.17	7
89.7	0.20	7
99.8	0.30	6
109.7	0.27	6
119.2	0.36	6
128.5	0.28	6
137.5	0.39	5
146.3	0.83	3
154.9	0.77	3
159.1	0.65	3

E_d=15.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.3	0.70	2
34.9	0.90	2
46.3	0.80	3
57.5	0.32	5
68.5	0.31	5
79.2	0.15	7
89.7	0.21	6
99.8	0.33	6
109.7	0.23	6
119.2	0.33	5
128.5	0.27	6
137.5	0.26	6
146.3	0.50	6
154.9	0.55	6
159.1	0.40	6

E_d=16.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.3	1.21	1
29.1	1.31	1
34.9	1.29	1
40.6	1.20	2
46.3	0.86	2
51.9	0.49	3
57.5	0.28	4
63.0	0.26	4
68.5	0.34	4
73.9	0.30	4
79.2	0.23	6
85.5	0.16	7
89.7	0.19	7
94.8	0.32	5
99.8	0.40	5
104.8	0.34	5
109.7	0.25	6
114.5	0.21	7
119.2	0.24	7
123.9	0.28	7
128.5	0.29	7
133.0	0.23	7
137.5	0.19	7
141.9	0.17	7
146.3	0.29	7
150.6	0.45	7
154.9	0.54	7
159.1	0.51	7

Table 2. (continued)

E_d=16.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.4	1.13	3
34.9	1.03	1
46.3	0.93	2
52.0	0.55	3
57.6	0.32	3
63.1	0.32	5
68.5	0.46	4
74.0	0.55	3
79.3	0.40	3
84.6	0.23	6
89.7	0.18	6
94.8	0.24	6
99.9	0.29	5
109.7	0.25	6
119.3	0.18	7
128.5	0.23	6
137.6	0.32	4
146.3	0.51	4
154.9	0.64	3
159.2	0.67	3

E_d=16.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.4	1.19	3
34.9	0.87	3
40.7	0.97	3
46.4	0.79	3
50.8	0.64	3
57.6	0.34	4
63.1	0.37	5
68.6	0.51	3
79.3	0.49	3
89.8	0.29	5
99.9	0.22	6
109.8	0.14	8
119.3	0.13	8
128.6	0.11	7
137.6	0.29	4
142.0	0.47	5
146.4	0.58	2
154.9	0.68	3
159.2	0.68	2

E_d=17.3 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.4	1.25	2
34.9	0.72	2
40.7	0.68	2
46.4	0.63	3
52.0	0.42	3
57.6	0.31	3
68.6	0.57	3
79.3	0.43	4
89.8	0.22	6
99.9	0.25	6
109.8	0.12	8
119.3	0.09	10
128.6	0.10	9
137.6	0.25	6
146.4	0.49	4
154.9	0.57	3
159.2	0.46	3

E_d=18.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.4	0.90	2
29.2	0.76	2
35.0	0.65	2
40.7	0.65	2
46.4	0.65	3
52.0	0.51	3
57.6	0.34	4
63.2	0.25	5
68.6	0.27	5
74.0	0.25	5
79.4	0.28	5
84.6	0.28	5
89.8	0.26	6
100.0	0.29	5
109.8	0.14	8
119.4	0.10	9
128.6	0.11	9
137.6	0.19	6
146.4	0.38	5
155.0	0.26	6
159.2	0.16	7

Table 2. (continued)

E_d=18.8 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
17.5	0.81	8
23.4	0.62	6
29.2	0.40	5
34.9	0.33	5
40.7	0.51	6
46.3	0.65	6
52.0	0.61	6
57.6	0.43	5
68.6	0.19	3
79.3	0.21	4
89.8	0.28	4
99.9	0.32	2
109.8	0.22	3
119.3	0.26	2
128.6	0.22	5
137.6	0.31	2
146.3	0.55	3
154.9	0.37	4
159.2	0.23	4

E_d=19.6 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
17.5	1.05	10
23.4	0.70	9
29.2	0.35	9
34.9	0.30	11
40.7	0.50	14
46.4	0.60	14
52.0	0.53	14
57.6	0.34	11
68.6	0.14	9
79.4	0.18	9
89.8	0.22	11
100.0	0.18	6
109.8	0.17	4
119.4	0.16	5
128.6	0.16	3
137.6	0.27	2
146.4	0.38	4
155.0	0.29	4
159.2	0.19	5

Table 2. (continued)

(b) O^{16} (d,α_2) N^{14} 2nd

E_d=14.9 MeV

$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.8	1.67	2
29.7	2.57	1
35.6	2.74	2
41.4	1.82	2
47.2	0.77	2
58.6	0.43	3
69.7	0.64	3
80.6	1.04	4
91.1	1.18	4
101.2	0.84	4
111.1	0.50	5
120.6	0.59	6
129.7	0.98	6
138.6	0.75	6
147.2	0.60	6
155.6	0.94	6
159.7	0.98	6

E_d=15.4 MeV

$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
17.9	2.00	1
23.8	1.79	1
29.7	1.89	2
35.6	1.73	2
41.4	1.31	3
47.2	0.61	3
58.6	0.31	3
69.7	0.63	4
80.6	1.03	4
91.1	1.22	4
101.2	0.84	5
111.1	0.55	5
120.6	0.70	5
129.7	1.08	4
138.6	0.86	4
147.2	1.14	4
155.6	1.96	4
159.7	1.99	4

E_d=15.7 MeV

$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.8	2.05	2
35.6	1.99	2
47.2	0.57	4
58.6	0.23	5
69.7	0.63	4
80.6	1.01	4
91.1	1.27	4
101.2	0.96	4
111.1	0.68	6
120.6	0.80	6
129.7	1.17	6
138.6	0.94	8
147.2	1.27	8
155.6	2.40	8
159.7	2.40	8

E_d=16.0 MeV

$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.8	2.72	1
29.7	2.48	1
35.6	1.88	3
41.4	1.05	3
47.2	0.43	3
52.9	0.18	5
58.6	0.34	5
64.2	0.62	4
69.7	0.87	4
75.2	0.85	4
80.6	0.79	4
85.9	0.92	4
91.1	1.07	4
96.2	1.26	4
101.2	1.19	4
106.2	1.02	4
111.1	0.76	5
115.9	0.71	7
120.6	0.80	7
125.2	0.95	8
129.7	1.06	8
134.2	0.89	10
138.6	0.76	10
142.9	0.63	10
147.2	0.78	10
151.4	1.04	10
155.6	1.75	10
159.7	1.97	10

Table 2. (continued)

E_d=16.5 MeV		
$\theta_{\mathrm{C.M.}}$ degree	$(d\sigma/d\Omega)_{\mathrm{C.M.}}$ mb/sterad	Error %
23.8	2.45	5
35.6	1.80	3
47.2	0.46	3
52.9	0.28	4
58.6	0.31	3
64.2	0.68	3
69.7	0.82	3
75.2	0.79	3
80.5	0.72	4
85.8	0.75	4
91.1	0.82	4
96.2	0.85	4
101.2	0.77	4
111.1	0.58	4
120.5	0.66	5
129.7	0.57	10
138.6	0.28	10
147.2	0.32	14
155.6	0.93	10
159.7	0.91	12

E_d=16.9 MeV		
$\theta_{\mathrm{C.M.}}$ degree	$(d\sigma/d\Omega)_{\mathrm{C.M.}}$ mb/sterad	Error %
23.8	1.98	3
35.6	1.96	3
41.4	1.20	3
47.2	0.70	3
51.8	0.46	3
58.6	0.45	3
64.6	0.61	4
69.7	0.61	3
80.5	0.76	3
91.0	0.59	4
101.2	0.55	4
111.0	0.63	6
120.5	0.52	8
129.7	0.38	14
138.6	0.19	15
142.9	0.26	14
147.2	0.30	14
155.6	0.36	7
159.7	0.36	11

E_d=17.3 MeV		
$\theta_{\mathrm{C.M.}}$ degree	$(d\sigma/d\Omega)_{\mathrm{C.M.}}$ mb/sterad	Error %
23.8	1.87	2
35.6	1.79	1
41.4	1.09	2
47.2	0.66	2
52.9	0.52	3
58.6	0.45	3
69.7	0.58	3
80.5	0.75	3
91.0	0.59	4
101.2	0.50	4
111.0	0.48	4
120.5	0.41	5
129.7	0.19	7
138.6	0.17	10
147.2	0.26	5
155.6	0.22	6
159.7	0.24	6

E_d=18.1 MeV		
$\theta_{\mathrm{C.M.}}$ degree	$(d\sigma/d\Omega)_{\mathrm{C.M.}}$ mb/sterad	Error %
23.8	0.91	2
29.7	1.65	2
35.6	1.38	2
41.4	0.75	2
47.2	0.57	4
52.9	0.71	2
58.6	0.68	3
64.2	0.49	3
67.7	0.32	4
75.2	0.40	4
80.6	0.59	4
85.9	0.68	3
91.1	0.55	4
101.2	0.25	6
111.1	0.26	6
120.6	0.33	6
129.7	0.43	5
138.6	0.34	5
147.2	0.28	5
155.6	0.27	5
159.7	0.17	6

Table 2. (continued)

E_d=18.8 MeV			E_d=19.6 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %	$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
17.8	0.83	5	17.8	1.39	5
23.8	0.74	4	23.8	0.97	6
29.6	1.27	4	29.7	1.41	10
35.5	1.21	6	35.5	1.14	9
41.3	0.77	8	41.3	0.57	9
47.1	0.58	6	47.1	0.31	14
52.8	0.57	5	52.8	0.41	20
58.5	0.45	5	58.5	0.42	11
69.5	0.43	6	69.6	0.32	8
80.4	0.53	4	80.5	0.45	6
90.9	0.37	3	91.0	0.32	7
101.0	0.24	2	101.2	0.18	6
110.9	0.14	2	111.0	0.08	6
120.4	0.22	3	120.5	0.18	3
129.6	0.33	5	129.6	0.42	2
138.4	0.37	2	138.5	0.40	2
147.1	0.18	2	147.1	0.32	2
155.5	0.29	3	155.5	0.63	4
159.7	0.51	4	159.7	0.84	5

Table 3. Integrated cross sections for the reaction C^{12} (d,α) B^{10}

E_d MeV	α_0 mb	α_1 mb	α_3 mb	α_4 mb
15.1	30.7	37.6	12.3	13.2
15.9	33.0	30.9	11.1	10.7
16.7	32.9	20.5	11.3	12.0
17.5	29.4	15.8	10.1	10.5
18.2	29.1	14.8	8.9	8.3
19.0	27.0	13.5	8.1	7.8
19.7	23.4	12.6	6.6	8.1

Table 4. Integrated cross sections for the reaction O^{16} (d,α) N^{14}

E_d MeV	α_0 mb	α_2 mb
14.9	7.0	12.1
15.4	5.7	12.9
15.7	4.9	13.5
16.0	5.7	13.2
16.5	5.9	10.5
16.9	5.7	9.0
17.3	5.1	8.1
18.1	4.2	6.3
18.8	4.3	5.6
19.6	3.6	5.5

3. DISCUSSION

Recently, Honda, Horie, Kudo and Ui[7] analyzed our experimental results on the O^{16} (d,α) N^{14} reaction. They used cut-off Born approximation and assumed that foward angle distribution comes from the pick-up process and that the backward angle distribution is due to the heavy particle stripping mechanism. They got good agreement with the experimental results without using any energy dependent parameters. They also found that the effect of antisymmetrization played an essential role to resemble the angular distribution.

Our interpretation is given in the reference[5], on the C^{12} (d,α) B^{10} reaction and also on the O^{16} (d,α) N^{14} reaction.

Afterall, it may be suggested that the alpha particle clustering in the C^{12} and O^{16} nucleus play an important role in these reactions, and that the reactions show almost smooth energy dependency, but some anomalies should be noticed, which appeared in the C^{12} (d,α) B^{10} reaction at the deuteron energies from 15 to 17 MeV and in the O^{16} (d,α) N^{14} reaction at the deuteron energies near 16 MeV.

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